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(54) **Frequency Converting Arrangement**

(57) The arrangement makes use of a rotary dynamo-electric machine (6) having stator and rotor windings (7, 5) wound as for a wound-rotor induction motor with one of the windings connected, for example via a control device (3) to the output of a three-phase generator (1), e.g. a wind or tidal power generator, having a first frequency which may vary, and the other connected to conductors (9) of a three-phase supply of substantially constant frequency e.g. the National Grid. Then, provided the output power of the generator (1) exceeds a certain value, power at said supply frequency will be fed back into the supply irrespective of the generator frequency. The use of slip-rings (4) can be avoided by replacing the induction machine with two similar machines having their rotor windings interconnected and the stator windings connected to the generator and supply respectively.

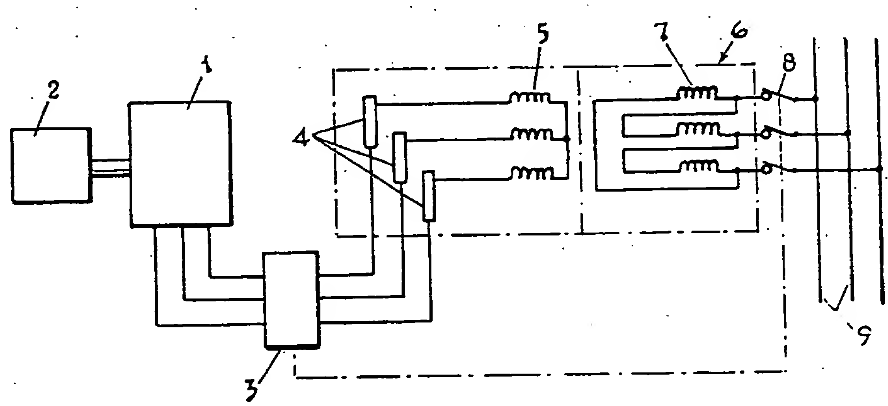

FIG.1.

The drawings originally filed were informal and the print here reproduced is taken from a later filed formal copy.

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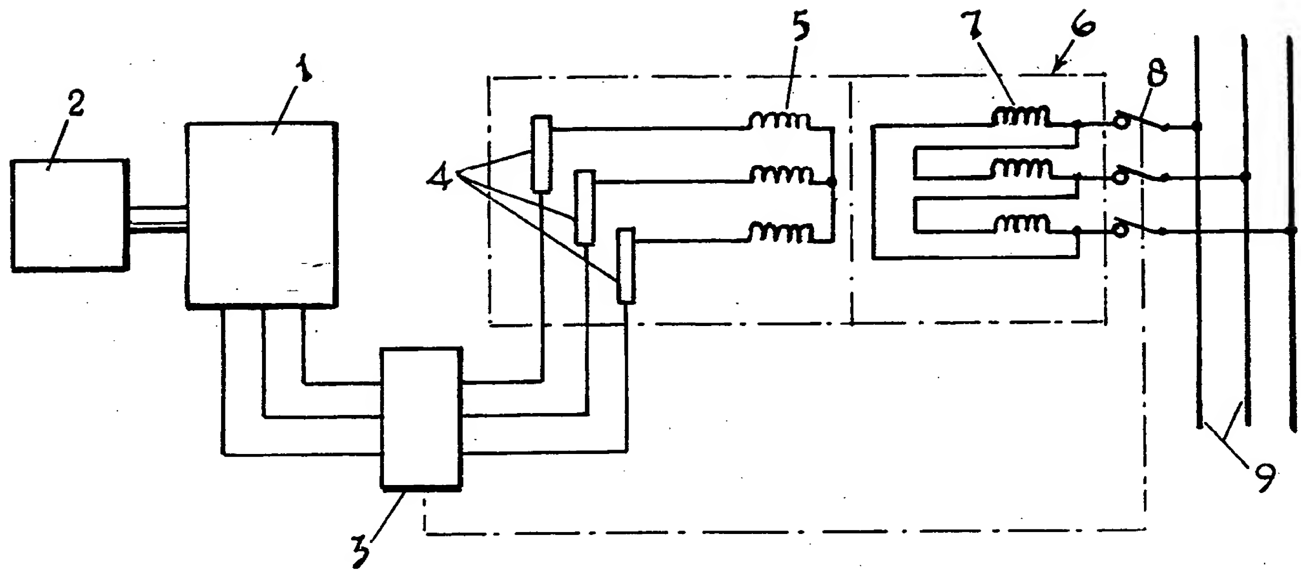

FIG.1.

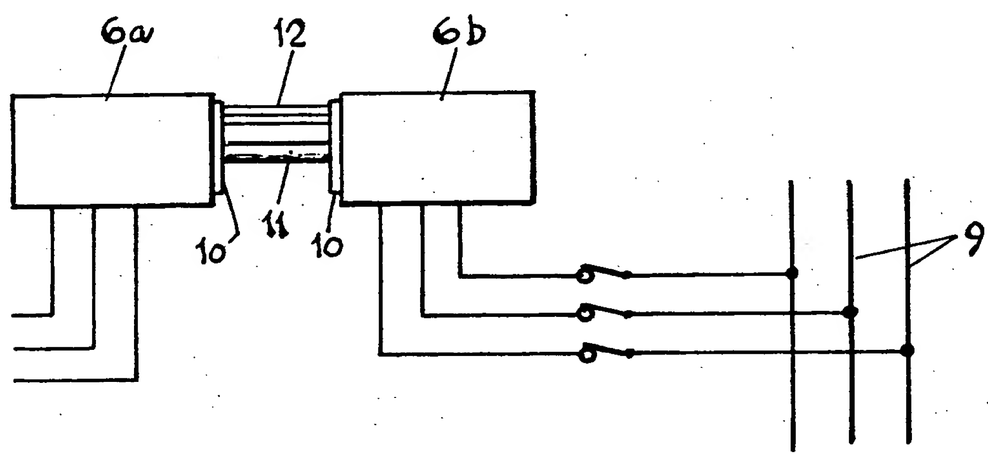

FIG.2.

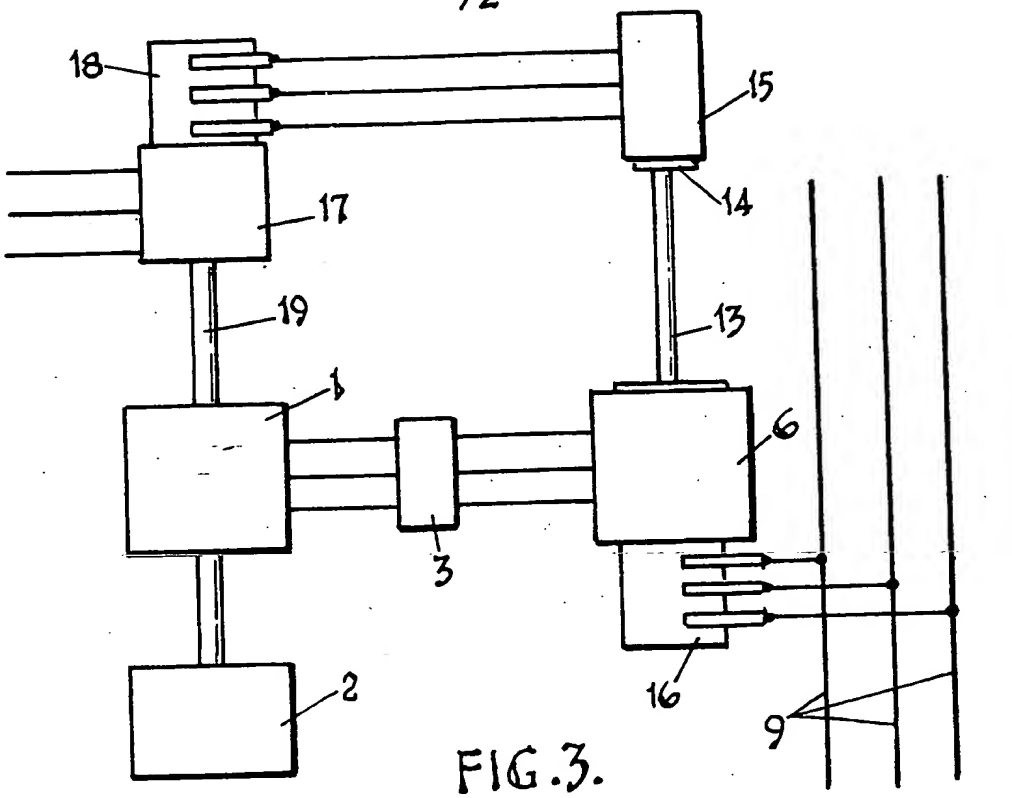

FIG.3.

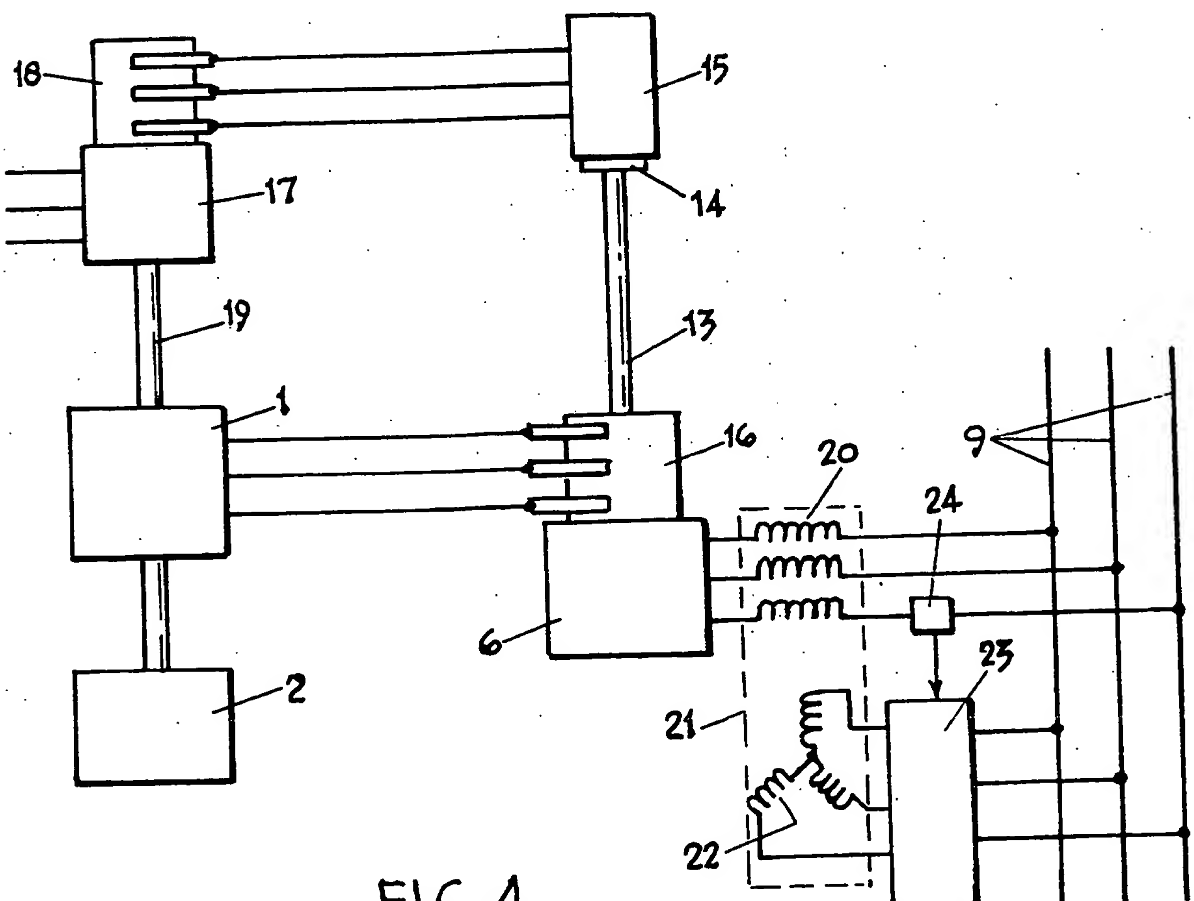

FIG.4.

SPECIFICATION
Frequency Converting Arrangements

This invention relates to frequency converting arrangements, more especially, though not exclusively for deriving from an electrical generator operating at varying speeds alternating current of substantially constant frequency.

Thus on some types of power generation equipment the rotational speed of the AC generator varies widely and in a random manner. Such applications include the harnessing of wave, wind, and tidal power. In order to feed this power into the National Grid or to parallel a number of generators onto a common bus, the random frequency outputs from these generators must be converted to a common standard, that is, 50 H_z in this country. With present day technology the first approach would be to use a static method of conversion (rectifying and inverting) but this has still certain limitations regarding maximum available rating, cost, reliability, and control complexity.

According to one aspect of the invention a frequency converting arrangement incorporates a rotary dynamo-electric machine having stator and rotor windings wound as for a wound-rotor induction motor, one of said windings being connected to the output of a three-phase generator having a first frequency, which may vary, and the other of said windings being connected to conductors of a three-phase alternating current supply of substantially constant frequency.

It has been found that provided output voltage of the generator exceeds a certain value, power at said substantially constant frequency will be fed back into the supply, the dynamo-electric machine acting, in effect, as a rotary frequency transformer. Moreover the power fed back to the supply will be at the supply frequency independently of the input frequency, as long as the speed of rotation of the rotor remains within normal synchronous torque limits.

Means can be provided for automatically cutting-off the machine from the constant frequency supply in the event of the voltage produced by the generator falls below said predetermined value, to avoid taking power from the supply when output voltage of the said generator is below the predetermined value.

According to another aspect of the invention a frequency converting arrangement incorporates a pair of rotary dynamo-electric machines each having stator and rotor windings wound as for a wound-rotor induction motor, with the rotors rotatable together, for example by being mounted on a common shaft, and their windings connected in series, and the stator winding of one machine being connected to the output of a three-phase generator having a first frequency, which may vary, and the stator winding of the other machine being connected to conductors of a three-phase alternating current supply of substantially constant frequency.

This arrangement also acts as a rotary frequency transformer and provides a way of obtaining power at the supply frequency from a variable frequency input and has the advantage over the previous arrangement that no slip rings are required for providing connections to the rotor windings. The two rotary machines can, of course be combined in a single unit.

In each of the arrangements above described means are preferably provided for preventing the rotor speed from falling out of step beyond the normal synchronous torque limits. Such means may, for example, comprise a normal induction motor coupled to the shaft of the rotary frequency transformer, provided by the dynamo-electric machine or machines, and fed with an alternating current of an appropriate frequency as will subsequently be described.

Due to the high reactance in an induction motor the power transfer in arrangements as above described would tend to have a low power factor. This may be corrected by inserting series resistance in the output, thus changing the proportions of the reactive and power components of the transferred KVA. The improvement in power factor largely compensates for the inherent losses in the series resistance.

However these losses can be recovered by simulating the series resistance using a bucking transformer having secondary windings in the output of the system, and primary windings controlled by a controller in response to the output current. Thus by closed loop control the voltage on the secondary of the transformer can be maintained proportional to and in phase with the instantaneous output current, the power from the simulated resistance being fed into the supply system.

It may transpire that laws other than resistive give a superior performance for some applications, and this latter arrangement can also be used to provide such a required alternative law, by the choice of appropriate elements.

The means for driving the generator, in an arrangement in accordance with the invention, may, for example, be in form of a turbine or other device arranged to be driven by wave, wind or tidal power, although the invention is applicable to arrangements utilising any form of three-phase alternating current generating systems in which the frequency of the current is liable to fluctuations.

Four embodiments of the invention will now be described by way of example with reference to Figures 1 to 4 of the accompanying schematic drawing.

Thus referring first to Figure 1, the first embodiment of the invention comprises a three-phase alternating current electrical generator 1 coupled to a device 2, for example a wave or wind driven turbine, which drives the generator at varying speeds, so producing an output current of varying frequency.

This three-phase current is fed, via a control

device 3 and slip ring connections 4, to the rotor winding 5 of a rotary dynamoelectric machine 6 having rotor and stator windings wound as for an induction motor. The stator winding 7 of the machine is connected by switches 8 to bus-bars 9 of a 50 H_z alternating current supply.

Now a characteristic of an induction motor is that the sum or difference of the frequencies of the stator and rotar currents is proportional to the shaft speed. That is to say

$$N=\frac{F_1 \pm F_2}{P}$$

where

N=shaft speed (revolutions per second)

F_1=stator current frequency (H_z)

F_2=rotor current frequency (H_z)

P=number of pole pairs

When run as an induction motor the rotor frequency is not fixed and takes up a value dependant upon the motor shaft torque. However if, as shown in Figure 1, the output of the variable frequency generator 1 is connected to the rotor winding 5 of the machine 6 via the slip rings, and the bus-bars 9 of the constant frequency supply are connected to the stator winding 7, the rotor speed will be determined by the sum or difference of the two frequencies, depending upon the relative phase rotations.

That is,

$$N=\frac{F_s \pm F_g}{P}$$

where

F_s=frequency of feed from supply

F_g=frequency of feed from generator

It has been found that by suitable control of the output voltage of the variable frequency generator, power flow from the generator 1 through the machine 6 to the supply will be obtained the machine acting in effect as a frequency transformer. Since there is no mechanical coupling to the rotary transformer the output shaft employed on conventional induction motors can be omitted. It should be noted that the variable frequency supply could equally well be connected to the stator winding 7 and the constant frequency supply to the rotor winding 5.

As a refinement of the system, should it be desirable to omit the use of slip rings, two rotary transformers 6a, 6b similar to that of Figure 1; with their rotors 10 mounted on the same shaft 11 and connected in cascade can be used as shown in Figure 2. The stator winding of the rotary transformer 6a is connected to the output of the variable frequency generator (not shown) and the stator winding of the transformer 6b is connected to the bus-bars 9, the rotor windings being connected in series by suitable link conductors represented diagrammatically at 12.

This arrangement operates in a similar manner to the arrangement illustrated in Figure 1, although the efficiency of this arrangement would be somewhat lower than that of the single machine.

In this second embodiment, however, the combined rotor speed becomes:—

$$N=\frac{F_s \pm F_g}{2P}$$

The machine thus operates in a synchronous mode, at an effective frequency of $F_s \pm F_g$.

The third embodiment of the invention illustrated in Figure 3 comprises a single rotary transformer 6 as in the arrangement illustrated in Figure 1, although in this case the rotor shaft 13 carries the rotor 14 of a conventional induction motor 15. The output of the variable frequency generator 1 is connected to the stator winding of the transformer 6 and the supply bus-bars 9 to the winding of the rotor 16 via slip rings, although these connections can be reversed.

There is also provided an auxiliary rotor transformer 17 having its rotor mounted on the shaft 19 of the generator 1, and its rotor winding connected to the stator winding of the motor 15. The stator winding is connected to the supply bus-bars 9.

In use of the arrangement a current of variable frequency $F_s \pm F_g$ is fed to the stator of the motor 15 and the purpose of this arrangement is to prevent the rotor speed falling out of step beyond the normal torque limits.

Again slip rings can be omitted from the transformer unit by utilising two transformers in the manner of Figure 2. In this case, using two pole configurations, for the latter, the variable frequency generator 1 and the induction motor 12 would require to have four poles, because they would be running at half speed.

Now since induction motors inherently have a high reactance the power transfer of the simple arrangements above described would tend to have a low power factor. However this can be corrected by inserting series resistance in the output of the rotary transformer 6, so as to change the proportions of the reactive and power components of the transferred KVA, the improvement in power factor conpensating for losses in the series resistance.

An alternative method of correction is illustrated in Figure 4, which represents a modified form of the arrangement shown in Figure 3.

In this fourth embodiment the secondary winding 20 of a bucking transformer 21 is connected in series with the output of the rotary transformer 6, (which in this case is shown taken from the stator winding instead of the rotor winding as in Figure 3, but this is immaterial). The primary winding 22 of the transformer 21 is connected to the supply bus-bars 9 through a controller 23 responsive to a monitor device 24 on the output side of the transformer. The arrangement acts, in effect, as a closed loop

control, with the voltage on the secondary of the transformer 21 made to be proportional to, and in phase with, the instantaneous current. Accordingly it provides a simulated series resistance, and the power from this simulated series resistance is fed back into the bus-bar system.

Other arrangements are readily possible, and may be utilised in cases where laws other than resistive give a superior performance, the system being readily acceptable to provide a required law.

Claims

1. A frequency converting arrangement incorporating a rotary dynamo-electric machine having stator and rotor windings wound as for a wound-rotor induction motor, one of said windings being connected to the output of a three-phase generator having a first frequency, which may vary, and the other of said windings being connected to conductors of a three-phase alternating current supply of substantially constant frequency.

2. A frequency converting arrangement incorporating a pair of rotary dynamoelectric machines each having stator and rotor windings wound as for a wound-rotor induction motor, with the rotors rotatable together, and their windings connected in series, and the stator winding of one machine being connected to the output of a three-phase generator having a first frequency, which may vary, and the stator winding of the other machine being connected to conductors of a three-phase alternating current supply of substantially constant frequency.

3. A frequency converting arrangement according to Claim 1 or 2 incorporating an induction motor having its rotor coupled to the rotor of the dynamo-electric machine or machines, and arranged to be fed, in use, with an alternating current of a frequency such as to prevent the machine rotor speed falling out of step.

4. A frequency converting arrangement according to any preceding claim including means for cutting off the dynamo-electric machine or machines from the constant frequency supply in the event that the voltage produced by the generator falls below a predetermined value.

5. A frequency converting arrangement according to any preceding claim including a series resistance in the output conductors of the arrangement.

6. A frequency converting arrangement according to any one of Claims 1 to 4, including a bucking transformer having secondary windings connected in series with the output conductors of the arrangement, and primary windings controlled by a controller in response to the output current.

7. A frequency converting arrangement according to any preceding claim wherein the generator rotor is coupled to a turbine or other rotary device arranged to be driven by wave, wind or tidal power.

8. A frequency converting arrangement substantially as shown in and as hereinbefore described with reference to any one of Figures 1 to 4 of the accompanying drawings.

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